
**ORIGINAL CONTAINS
COLOR ILLUSTRATIONS**

Impacts of Sociopolitical Conditions

Ben R. Finney

S3-91
140703
P-14

To what extent will scenarios of space development, and the choice of technologies to carry these out, hinge upon future social, economic, and political factors outside the range of currently discussed scientific and commercial rationales for venturing into space? Outside factors have greatly influenced the course of space development in the past—as witness the initial drive to develop large rockets and the subsequent race for the Moon. Although space technology has now reached a level where it has demonstrable scientific and commercial utility, there is no reason to assume that this utility must exclusively or even largely determine the course of space development.

We should be prepared to consider how changing conditions, outside of space development per se, may impact that development. For example, an emphasis on space weaponry, and defense against that weaponry, might lead to a significant requirement for lunar or asteroidal materials for shielding. Alternatively, superpower rivalry might once again be expressed in peaceful competition in space, where the goal of setting up the first Moon or Mars base could

override the logic of orderly, evolutionary development. Or a global environmental crisis might stimulate an effort to magnify remote sensing capabilities and lead to the revival of the solar power satellite concept. Geopolitical developments might lead to major international cooperation in space—such as between the United States, Europe, and Japan or between the capitalist and socialist blocs or between First World and Third World nations or some combination of these. Finally, a major cultural upheaval—such as might be occasioned by the discovery, through NASA's Search for Extraterrestrial Intelligence (SETI) program, of intelligence in some other star system—could dramatically impact our conception of the human role in space.

It is, of course, impossible to predict the future. However, any scenario of space development, and the technology requirements engendered, in effect assumes a future vision—not only of that development but also of outside forces and events. Space development scenarios are inherently part of larger scenarios of human development.

Common Technologies

Terry Triffet

Common to the baseline and alternative scenarios presented above are a number of intersecting or nodal technologies. That is, regardless of whatever divergent paths such developments may take, they will intersect at these points and cannot move beyond them until certain problems specific to these technologies have been solved. Thus, in a sense, these nodes are the invariants of the system, and concentrating attention on them should be the most efficient way to proceed. It is a primary purpose of this study to point to these pivotal technologies and highlight their barrier difficulties.

Transportation

Surely the most fundamental nodal technology, because of its high leverage on the entire evolution of space development, is transportation. The cost of delivery into low Earth orbit, which had been moving downward as a result of Space Shuttle efficiency, is now, as a result of the *Challenger* accident, estimated to be over \$3000 per pound and the extrapolated cost for delivery to the Moon over \$20 000 per pound.

Technologies that have been proposed to cut delivery costs to low Earth orbit and beyond fall into three categories: (1) improvements to the performance of earthlift

vehicles, (2) development of space-based orbital transfer vehicles and associated propulsion technologies, and (3) production of propellants using nonterrestrial resources.

Complex system tradeoffs are required to determine which approach will be optimal in a given scenario. For example, reducing the cost of Earth-to-orbit (ETO) transportation will reduce by a similar proportion the cost of Earth-to-Moon transportation and will thus reduce the cost of obtaining propellants from the Moon. However, if the ETO costs are reduced enough, the expense of establishing a lunar facility to produce propellant to reduce transportation costs may not be merited. Aspects other than transportation costs may need to be considered. For example, at some level of activity, modification of the Earth's environment due to high launch rates may become intolerable.

The first objective in all scenarios is to reduce the cost of ETO options. The general approach is well understood, and several options are discussed later in this report. Expected costs for various options are given in table 6. Shuttle-derived launch vehicles are a class of vehicles in which the manned elements of the Space Shuttle are replaced by cargo-carrying capacity (see fig. 18). Heavy lift vehicles apply Space Shuttle propulsion

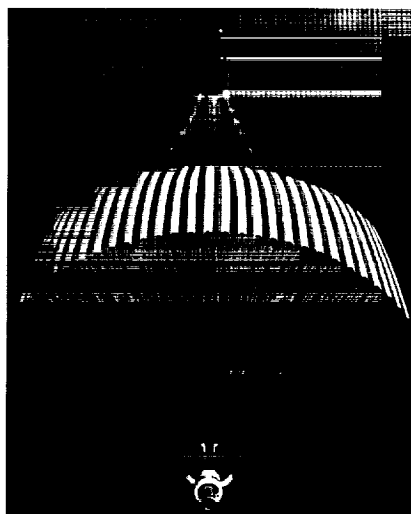
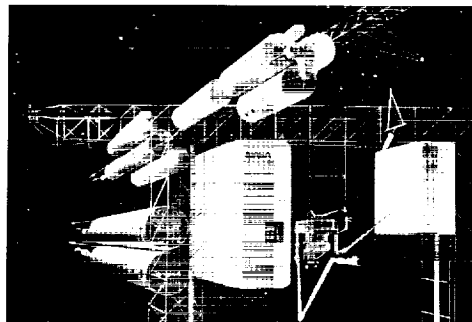
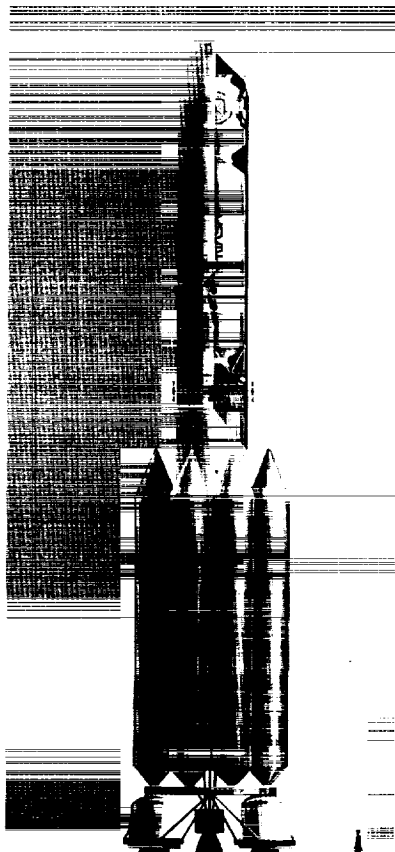


Figure 18

Consort

Since the Challenger accident, it has become increasingly clear that unmanned launch vehicles must be developed to transport large cargoes into space at relatively low costs. In the concept shown here, the liquid-fueled Consort vehicle is launched into space with five Space Shuttle main engines. At the staging point in the ascent, four of these engines are jettisoned, returned to Earth by remote-controlled parachutes, recovered dry by a ship with arresting gear, and reused. The eight strap-on oxygen and hydrogen tanks are also jettisoned and allowed to fall into the ocean. The second stage delivers its cargo housed in a Titan IV fairing. This second stage, which includes one Space Shuttle main engine, internal fuel tanks, and support equipment, might then become the basis of an orbital transfer vehicle.

Courtesy of Davis Aerospace Company

TABLE 6. Potential Earthlift Options

1. Space Shuttle	\$3300/lb
2. Shuttle-derived launch vehicle	\$500-1000/lb
3. Heavy lift vehicle	\$300-500/lb
4. Hybrid electromagnetic launches and rockets	< \$300/lb

Figure 19

"Fat Albert"

Another approach to the launch of heavy cargoes is a massive single-stage-to-orbit booster, such as "Fat Albert," from a 1976 design study. This booster has 48 engines, half of which burn liquid hydrogen and half of which burn rocket propellant type 1 (RP-1). After putting its cargo into low Earth orbit, the booster makes a deorbit burn, reenters the atmosphere, and then uses some of its engines to decelerate to near-zero velocity before touchdown in water, where it is recovered. Tradeoffs between boosters that are completely reusable and boosters that are totally expendable include complexity, design and manufacture costs, operation costs, and recovery and refurbishment costs. It is not always obvious which concept will ultimately be more cost-effective.

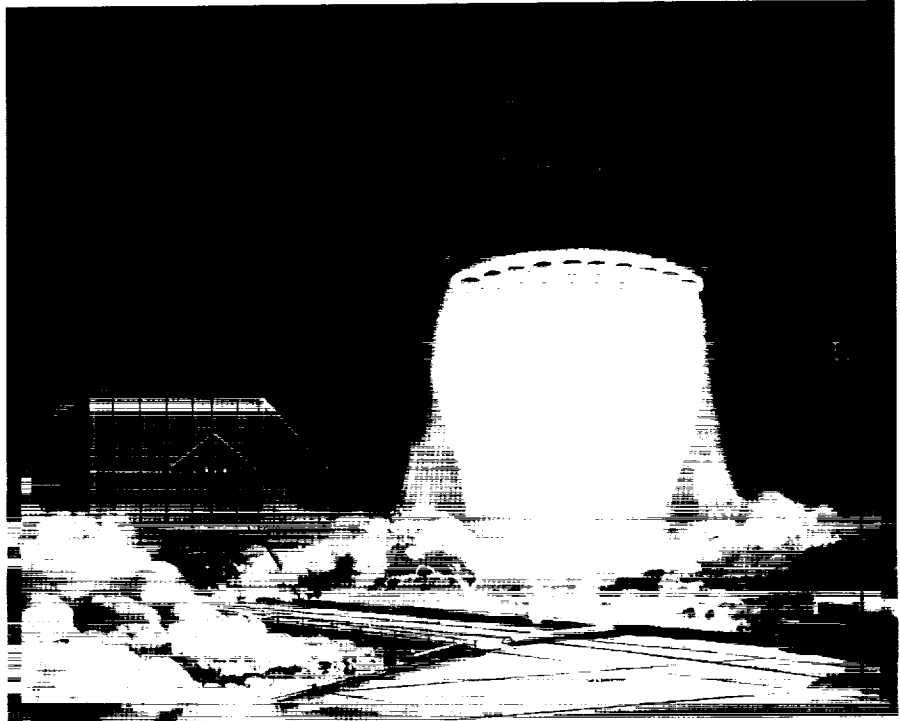


Figure 20

Lunar Orbit Space Station

Proximity to lunar-derived propellant and materials would make a space station in orbit around the Moon an important transportation node. It could serve as a turnaround station for lunar landing vehicles which could ferry up liquid oxygen and other materials from the lunar surface. An orbital transfer vehicle could then take the containers of liquid oxygen (and possibly lunar hydrogen) to geosynchronous or low Earth orbit for use in many kinds of space activities. A lunar orbit space station might also serve as a staging point for major expeditions to other parts of the solar system, including Mars.

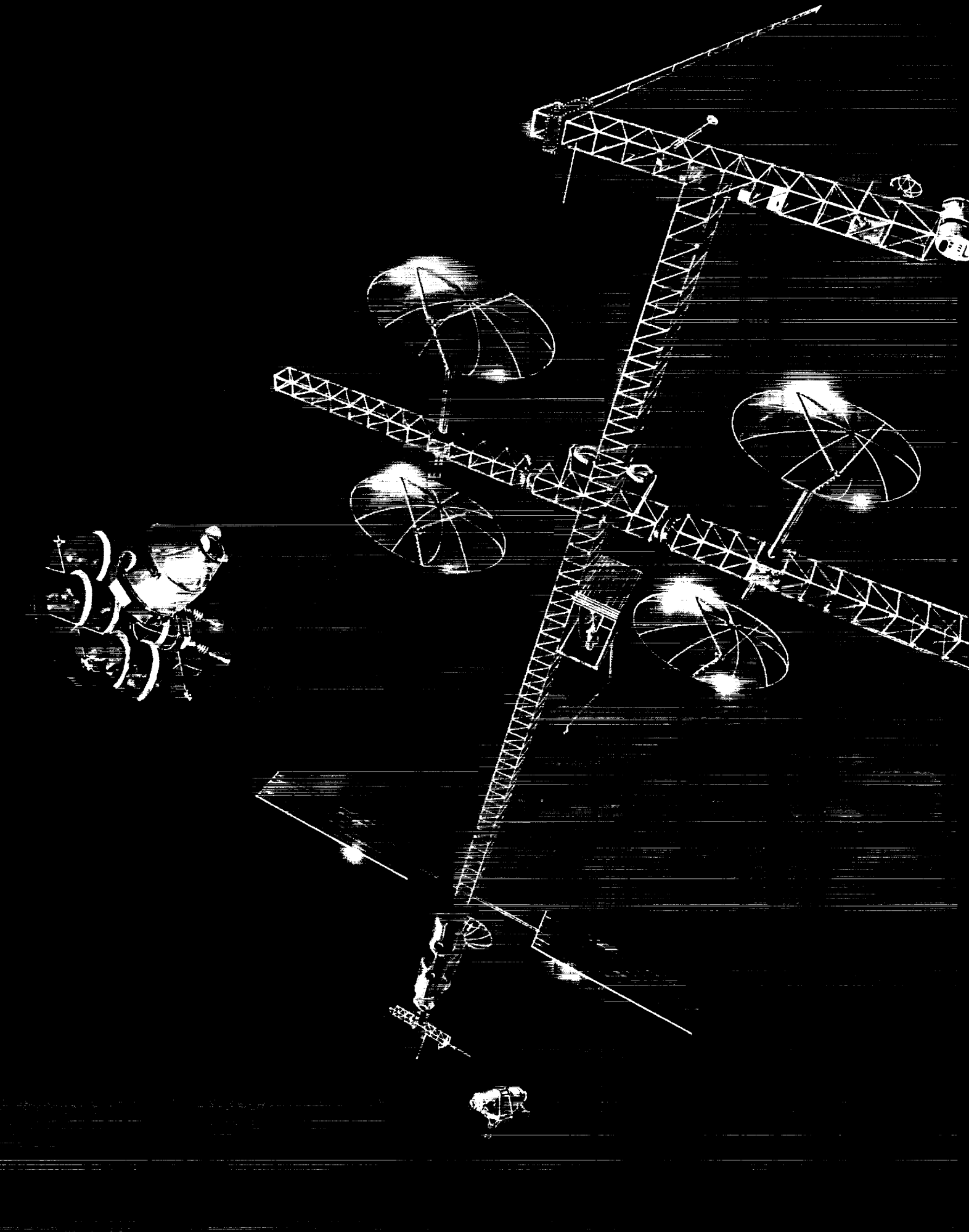
Artist: Michael Carroll

technology to a new class of large rockets (see fig. 19). Hybrid systems, air-breathing rockets, and electromagnetic propulsion technologies have also been studied.

Development and improvement of the performance of space-based orbital transfer vehicles involves propulsion technology, aerobraking technology, and lightweight structures. Aerobraking is a technology that replaces the propulsion system for deceleration upon return to Earth with an aerodynamic deceleration device. The task is to build an aerodynamic braking system that is lighter than

the propulsive braking system. Lightweight structures improve performance by exchanging vehicle weight for payload weight. The payoff is almost always greater than 1 pound of payload for each pound of structure, because structure must be carried throughout all the vehicle's velocity changes whereas the payload is usually dropped off somewhere along the way.

Propulsion technology for orbit-to-orbit transportation involves a wider variety of options because low-thrust systems are usable and the spacecraft do not have to travel through a planetary



atmosphere. The list of options in table 7 is most likely incomplete.

Using propellant produced in space for orbital transfer and lift-off from planetary surfaces is of interest because the energy required to achieve low Earth orbit from either asteroids or a lunar base is much lower than that required to fight the gravity well of Earth. (See figure 20.) For a system to be viable, the cost of developing and operating the nonterrestrial facility must be less than the cost of

delivering propellant from Earth. Thus, in general, the larger or more remote from Earth the usage, the more competitive the nonterrestrial resource will be.

Before costs can be assigned to the products, extensive development of process concepts and operational techniques is required. However, table 8 lists potential sources and types of propellants, which will be the focus for technology development.

TABLE 7. *Propulsion Technology Options for Orbital Transfer Vehicles*

1. Chemical - high performance O_2/H_2
2. Thermal - nuclear, solar, laser
3. Electric - ion accelerators, mass accelerators
4. Light - solar sails
5. Tethers - momentum storage and exchange, plasma dynamic thrusting and power production

TABLE 8. *Nonterrestrial Propellant Options*

1. Asteroids - water for liquid O_2 and liquid H_2
2. Moon - oxygen-hydrogen (Earth-supplied hydrogen), oxygen-silane (Earth hydrogen for silane), oxygen-aluminum (Earth-supplied binder)
3. Shuttle external tanks in orbit - aluminum and lunar or Earth oxygen
4. Electric propulsion - solar energy and nonterrestrial mass (lunar oxygen), electromagnetic accelerators and solid reaction mass, nuclear thermal energy and nonterrestrial mass, hybrid electromagnetic launchers and rockets

Energy

Equal in importance to transportation as a nodal technology is the development of energy sources in space. Space operations are impossible without appropriate power supplies; and any projects involving extended human activities in this hostile environment will necessarily be energy-intensive. Energy technology can be divided into two general classes: energy sources transported from Earth (chemical, nuclear) and those using in situ resources. Both classes will be utilized in the development scenarios considered.

Solar energy is usable as far out as Mars (and possibly Jupiter, using high concentrator systems). Beyond Jupiter, solar energy is too diffuse to be gathered in useful amounts. From there out, other sources, such as chemical and nuclear, are required.

The photovoltaic system with electrochemical storage has been the mainstay of space power to this time and will remain a serious contender for future space applications. This passive system is relatively maintenance-free and thus offers low life-cycle costs. Advanced photovoltaic systems, such as radiation-resistant indium phosphide cells and high-efficiency point-contact cells, promise greatly improved performance. Their

potential is further increased when they are coupled with storage systems with high energy densities, such as advanced regenerative fuel cells and innovative bipolar batteries.

Solar concentrators with dynamic systems (Stirling-, Brayton-, or Rankine-cycle thermal engines) offer an alternative to photovoltaic arrays. This technology becomes increasingly attractive as power demand goes up. The compactness of a solar thermal dynamic system is an advantage for missions subject to aerodynamic drag; its smaller cross section may significantly reduce the demand for orbit maintenance propellants. The ability of such a system to produce high point-source temperatures (several thousand versus one or two hundred degrees) make it a candidate for an integrated thermal electric distribution system; in such a system, the waste heat from the thermal engine could be piped in and used directly for onboard processes.

On the other hand, solar dynamic technology is less advanced than photovoltaic technology, and thus a greater development effort would be needed. Experience has been accumulated in solar Rankine systems, Brayton rotating machinery, and a Stirling free-piston engine. But problems remain in heat receiver design, materials compatibility, concentrator

design, and heat rejection and thermal control systems.

Nevertheless, because its power characteristics more closely resemble those of conventional sources, this alternative should be vigorously pursued.

Nuclear reactor energy sources deserve special mention (see fig. 21). Though posing formidable transport problems because of their mass, they offer high power levels, high temperatures, and long unattended operating times. In cases where solar energy is not continuously available (e.g., shadowed by Earth; on most of the lunar surface), a nuclear system may even have a mass advantage because a solar system would require an energy storage subsystem during shadowed periods. The shielding required to protect people from the radioactive energy source could, in planetary installations, be provided using local materials.

The technology underlying nuclear power is well understood, a large amount of Earth-operating experience has been accumulated, and miniaturization efforts are well advanced. Because this energy resource could take the greatest advantage of existing power technology, it, too, should be pursued with high priority. It could probably be ready for safe, reliable,

and versatile use before any of the others.

Technologies for transmission and delivery of power in space also require development. Use at or near the point of collection in space or on the Moon offers minimal technologic challenge. Beamed transmission (laser, microwave) is considered applicable on the Moon or from place to place in space. Rectenna development is under way. Transmission from space to Earth faces additional problems but may also be a viable concept.

A variety of other technologies bear on our ability to collect, condition, store, and utilize energy in space. Conversion of solar or nuclear energy through chemical processing to produce propellants is one of these. The use of tethers to transfer momentum is another. Storage of energy for use in peak periods and for solar energy systems with intermittent illumination (like the lunar surface) is especially important. These technologies and others may have significant roles in a mature space operations system.

With the advent of high-temperature superconductivity (now in the range of liquid nitrogen), many additional advances in space power systems are on the horizon. An example is superconducting

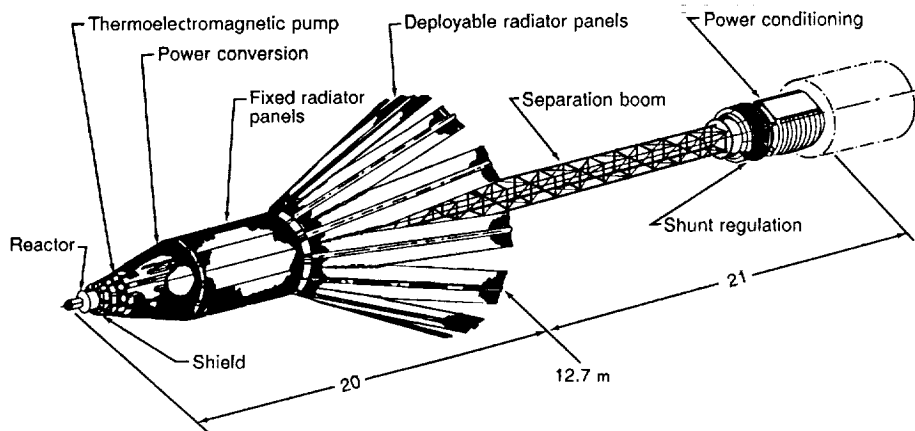
magnetic energy storage. Its advantages include high charge-discharge efficiency, less mass (because less refrigeration is required), and increased operating flexibility. If superconductor temperatures can be brought up to 0°C, the system, buried about 1 meter below the surface, could operate without any refrigeration through the lunar day/night cycle.

Other advances could improve future space power system applications. System control and monitoring by means of artificial intelligence could enhance autonomous power system operation. Advanced heat rejection systems such as the liquid droplet radiator could greatly reduce power system mass.

Figure 21

SP-100

The "SP-100" (not an acronym) is a nuclear power reactor for space applications. It has a nominal design power of 100 kW and uses a closed-cycle working fluid heated by the small reactor, thermocouples both to convert thermal energy to electric power and to operate the pump moving the working fluid, and both fixed and deployable radiators to reject the waste heat. Most of the cone-shaped structure in the illustration is radiator surface. Nuclear reactors are currently used in space to power some Soviet intelligence satellites. And radioisotope generators have been used in space for many years, including use on the Apollo lunar surface experiments package (ALSEP) and the Voyager spacecraft.



Computing Technology

Computing technology, or more specifically the development of software for knowledge-based information and control systems, is a critical area. In the case of manned operations, greatly improved systems are needed to reduce the number of humans required, complement their capability, and relieve them of hazardous and routine tasks. The natural first step should be to expand the capabilities of the computing system already central to every operation in space. This step would involve further reducing processing time and increasing main memory, while adding a more versatile communications interface and continuing to reduce the system's weight and physical dimensions. Ideally, in addition to its data collection and "housekeeping" management functions, this machine should offer access to an extensive body of mission-specific information, and each person present should have an open channel to it at all times. Moreover, this system should be capable of self-contained operation, in case communications with Earth are interrupted.

To accomplish all these improvements is well within the range of contemporary computing technology. Also within that range is the possibility of incorporating appropriate expert system programs which may make rapid,

error-free decisions and, if required, explain their reasoning. Together with instant access to a self-contained and specialized data base, this capability is essential to the success of even the simpler kinds of missions discussed above in the scenarios section. For the more complex missions, such as asteroid or lunar resource acquisition and processing, "intelligent" robotic assistance will be needed.

Given the present state of computing technology, it is entirely practical to target development of operational expert systems that incorporate strategic models and natural laws, weighted decision-making algorithms, and complex data frames, in addition to elementary inference engines, algorithms, and data bases of single facts. Such systems (see fig. 22) would possess the potential not only of assisting humans to make accurate, informed decisions under pressure but also of expanding the breadth and depth of human thought on this new frontier.

For extensive LEO, GEO, asteroidal, low lunar orbit, or lunar base operations, the economic advantages of using automated systems are plainly evident. These systems would be capable of supporting humans by making simple instant decisions, such as course- and handling-corrections based on sensor input, and of carrying out involved tasks under

remote control. No life support system or protective environment would be needed, exposure to hazardous conditions would be no problem, and boredom, no factor. We must stress that the recommended technology objectives are to develop more intelligent robots, not to eliminate humans from operations in space. Both are needed. Robot or automated systems are envisioned to be synergistic with humans (see fig. 23). Structuring the objectives in this way would greatly improve the chances of creating these sophisticated automatic systems within the time available.

Materials Processing

Materials processing technology is required to transpose to the space environment familiar terrestrial processes, such as mining, ore concentration, extraction of useful materials, and manufacturing (see fig. 24). Even though the specific processes to be developed are mission-dependent, materials processing in general must be regarded as fundamental, because it changes the nature of the space enterprise from dependence on the Earth for all materials to the degree of independence afforded by the use of indigenous materials. Some

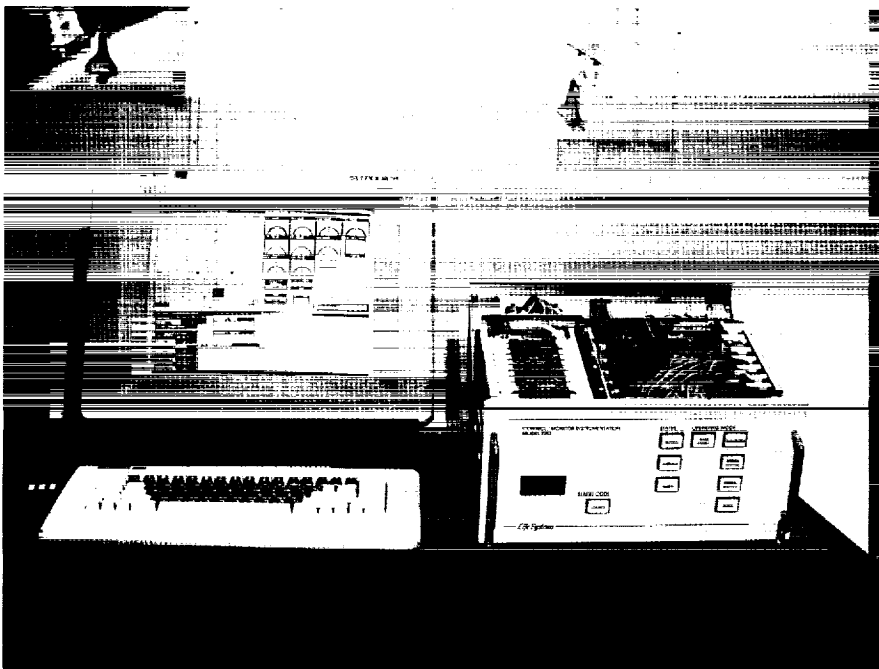


Figure 22

Expert System

"Expert system" is a term used to refer to an integrated computer and physical system in which very comprehensive software manages the system, handles a large variety of states and conditions, and even reacts to unexpected situations. Here is a prototype for an expert system that controls the removal of CO₂ from a space station habitation module. This system continuously monitors the CO₂ levels, gives instant readouts of environmental conditions from any terminal, provides feedback to reduce the levels as needed, and offers a variety of controls, checks, balances, and alarms on the condition of the environmental habitat atmosphere. As computer technology improves, such systems become more practical and less expensive.

Figure 23

Robot Rescuing an Astronaut on the Lunar Surface

Completely automated robots are a logical extension of comprehensive expert systems. Here, a robot with a contained expert system is rescuing a worker who has become ill while making a geological survey on the lunar surface. Although such robots could also be teleoperated from a control room, a completely automated version with a self-contained expert system might be the eventual goal. As the technology improves, teleoperated and expert system robots will become more and more useful for hazardous space activities, including lunar surface operations. Ultimately, many of the routine surface operations at a lunar base may be performed by such robots, leaving for humans the activities, such as scientific exploration, requiring very nonroutine observations and decisions.



Figure 24

Three-Drum Slusher

This lunar mining system is called a "three-drum slusher." It is similar to a simple two-drum dragline, in which a bucket is pulled by cables to scrape up surface material and dump it into a waiting truck. The third drum allows the bucket to be moved from side to side to enlarge the mining pit. Surface mining of unconsolidated lunar regolith, using versions of draglines or front-end loaders, will probably be done at a lunar base initially, although deeper "bedrock" mining is also a possibility and underground mining may even be attractive if appropriate resources are located.



missions would place heavy emphasis on the processing of mineral ores in space to recover useful metals, while others would place a premium on processing techniques aimed at the recovery of oxygen and hydrogen. Technologies in mining, materials handling, chemical extraction, storage, and manufacturing are applicable to various resources. Early development of these common technologies can improve the performance of the transportation, energy, and other systems.

Communications

Communications technology has already proven its worth and is at a relatively advanced stage of development. But further technological advances are possible in coupling communications equipment to computers, in developing large communication platforms in space, and in increasing the power and defining the focus of transmissions from space.

The economic, social, and political potential for worldwide applications of communications technology, particularly in Third World countries, is very great and should not be overlooked. Incremental advances in existing technologies should be sufficient to handle the communication and computing aspects, but the sociopolitical

problems involved in creating an enhanced global communications network are of a different order and beyond the scope of the present report.

New Technologies

We can take for granted that new methods and machines will be needed to adapt known techniques to operations in space. This almost amounts to a general principle: Old technologies will require new technologies in order to be applied in space (see fig. 25). What these needs may be cannot be known in advance, but allowances should be made to provide for them. Otherwise, time and cost overruns will inevitably result.

In this same vein, we should recognize that the development of entirely new technologies, such as those needed to effect weather/ climate control, atmospheric cleanup, or purging of the ionosphere, may prove to be desirable. These are massive undertakings and yet they cannot be disregarded. Like nearly continuous remote sensing of and almost instant communication with any point on Earth, these climate-control technologies are of enormous potential benefit to humankind. In the end, the successful accomplishment of any one of them could justify the entire space program.

Figure 25

Lunar Prospector?

One approach to the lunar environment is to simply modify old technologies somewhat to fit the new conditions. Here, that approach is taken to the extreme in this lunar resource prospecting system. The other extreme is to develop totally new technology, such as a completely automated expert system for lunar prospecting. The most workable approach is probably a compromise between old technology and new technology, using the best of both. What elements of this "old technology" are likely to be found at a lunar base in 2010?

